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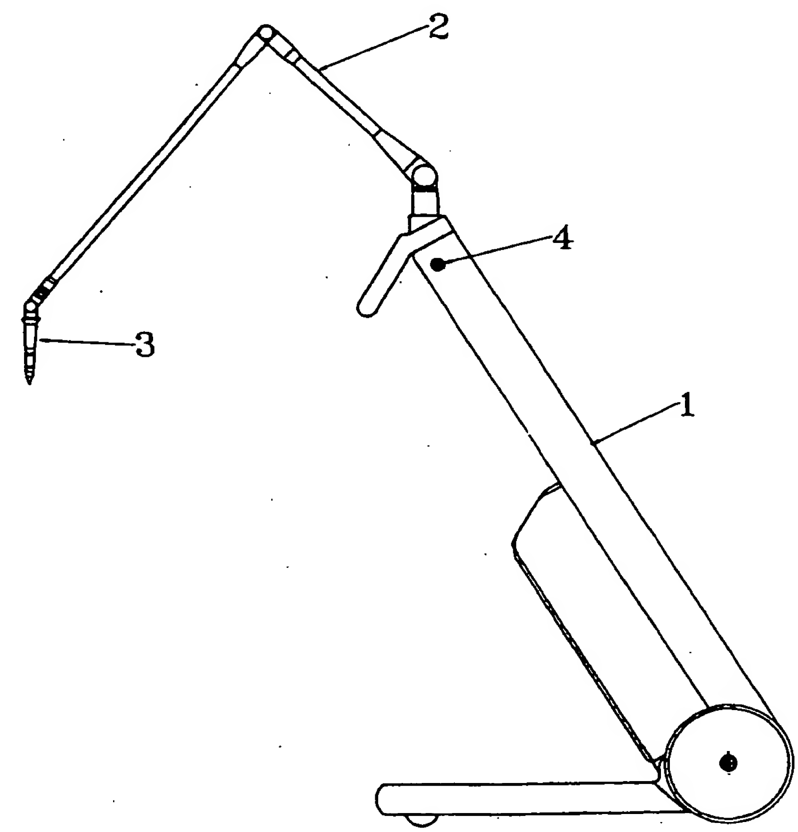
(54) Title: LASER SYSTEM

(57) Abstract

The invention relates to the application of lasers for controlled ablation of tissue, particularly but not solely for use in dentistry. The invention provides a CO_2 laser system comprising laser head, control means and scanning means wherein a laser beam is delivered in organised bursts of pulses to the tissue to be ablated.



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Laser System

The present invention relates to the application of lasers for the controlled ablation of tissue. More particularly the invention relates to the application of lasers in dentistry.

In this field it is known that certain lasers can be used to drill through hard biological tissue such as bone and the tooth enamel and dentine of teeth. In particular the Erbium:YAG laser operating at a wavelength of 2.94 μm, a wavelength that is especially strongly absorbed by water bearing tissue, has demonstrated efficient drilling without substantial damage to surrounding tissue when used in conjunction with a water spray. Such systems are now becoming available commercially. Short wavelength (0.19μm) Excimer lasers show a similar ability to provide clean cuts in tooth and bone tissue. These lasers provide relatively high energy pulses at a low repetition rate. Carbon dioxide lasers configured to operate in a similar way, that is with high energy short pulses (<10μs) at a low rate have also been reported to offer reasonably clean drilling although it is perceived that less strong water absorption at their wavelength of

10.6μm renders them less effective. It has been demonstrated that the far more common continuous wave (cw) or so-called "superpulse" CO_2 lasers overheat teeth with both undesirable carbon formation and potential damage to any underlying vital pulp.

These approaches have a number of disadvantages in terms of their application to dentistry. In particular the Excimer lasers are large and expensive requiring careful chemical engineering in the handling of their toxic gas constituents. This makes them entirely inappropriate for typical dental installations. Similarly the short pulse high energy CO_2 lasers, whilst common in industrial settings have no history of use in medical applications. The Erbium:YAG laser clearly can drill teeth effectively although it also is a relatively expensive system in the context of a typical dental installation.

The present invention aims to provide a method of drilling teeth with lasers which overcomes the aforementioned problems of the prior art.

According to the present invention there is provided a CO_2 laser system for ablation of tissue comprising a laser head, and control means whereby a focused laser beam is produced in organised bursts of pulses from the laser head to an area of tissue to be ablated.

Preferably the system further provides scanning means by which the focused beam traverses a defined area such as an area of tissue to be ablated.

Also according to the invention there is provided a method for the controlled ablation of tissue comprising the steps of delivering a focused laser beam from a CO_2

laser in organised bursts of pulses to the tissue to be ablated.

Preferably the method further comprises the step whereby the focused laser beam scans the area to be ablated.

Preferably the wavelength (λ) of the laser pulses is between 9 and 11μm.

Preferably pulse duration may be between 100-700μs.

Preferably between 1 and 10 pulses form a burst and pulses in a burst may be separated by between 200 and 1000μsec. More preferably pulse separation is between 25 and 600μs and most preferably 250-350μs.

Preferably burst repeat frequency may be between 10 and 100Hz.

More preferably burst frequency is between 30-50 Hz.

Preferably 10 to 50mJ of pulse energy is delivered in a beam focused to a diameter of typically 300μm.

As described herein the invention provides a method whereby effective drilling of all types of tooth tissue can be achieved with the output beam from suitably modified CO_2 lasers typical of those used commonly in medical applications.

To achieve clean drilling without either damage to adjacent tissue or subsequent cracking of enamel and dentine requires a specific organisation of the output into groups of pulses as described below. It is this specific grouping of pulses together with their

duration and profile which constitutes the successful activity of this invention. The relatively low energy pulses from such quasi-cw lasers can still produce efficient explosive ablation provided that the beam is focused down to a spot size of sufficiently small size. The invention may further provide a scanning means by which a small spot can traverse in an automatic preset fashion a pattern that gives the size of the drill hole characteristically required in dentistry. The timing of the grouped laser pulses on the scanned spot is achieved in such a way that a simple drilling action is perceived. This combination of specific arrangements of pulses in an output beam that is tightly focused and scanned provides a novel and non-obvious route to laser drilling of teeth using CO_2 lasers. The process as with current Er:YAG systems or standard mechanical drills requires the simultaneous presence of a fine water spray to assist in cooling.

Specifically it can be demonstrated that the following of features lead to the beneficial removal of dental hard tissue:

1. Pulsing of the laser for significantly lower durations than in the established "superpulse" mode.

2. Limiting the output to a burst of such pulses relatively few in number.

3. Providing a long enough gap between such bursts such that their advantageous characteristics are not affected.

4. Ensuring a strong interaction by tightly focusing the high quality beam onto the tissue.

5. Ensuring that the surfaces are maintained wet to further enhance the interaction and provide additional cooling.

In support of these individual aspects it can be argued that reducing the laser pulse duration to, for example 200μs enhances the relative contribution of the initiating spike to the overall pulse energy. The contribution from this spike is in any case greater in the first few pulses from an initial turn on due to the lack of ionised particles in the laser gas and the consequent need for more energy to initiate the discharge. By limiting the number of pulses delivered to a low number within a burst and further limiting the burst frequency such that each can be regarded as seeing an electrically cold gas, such an enhancement of the pulse power can be maintained. The level of enhancement depends on the position of a pulse within a burst; the first carrying a significant proportion of its energy within the short initiating spike (a few μs duration) and thus peak powers typically in excess of 200 watts, (in a laser giving around 20 watts when used cw), whilst subsequent pulses typically carry an increasing, but more uniformly distributed, energy. Overall the average power enhancement factor is typically x5 compared with the normal superpulse mode enhancement of x2.

The initial spike provides the high power which makes this mode of operation similar in its effectiveness on hard tissue to the previously mentioned purely pulsed CO_2 systems having durations of less than 10μs. Having initiated the interaction on tissue subsequent pulses within the burst provides the energy needed to remove significant volumes of material. In order to provide an effective drilling the burst must be repeated at a

sufficiently high rate to give significant material removal. This must be balanced by both the requirements of maintaining the characteristics of an individual burst and allowing the tissue immediately adjacent to the ablated region to cool.

The requirement for the successful ablation of any tissue is to supply efficient energy at a high enough rate to ensure removal of the affected zone before conduction processes have led to any potentially damaging heating of the surrounding area. This is achieved in dental hard tissues by using very high power densities, typically $50kW/cm^2$. In the case of our example here of a relatively low power cw equivalent laser this implies focusing to small spot size of around 0.3mm diameter. The appearance of a larger drill hole, as required to match conventional dental practice, together with further interpulse cooling of a given interaction volume is achieved by scanning the beam in for example a circular fashion such that an overall diameter of around 1mm is achieved. The gap between subsequent pulses over the same position is consequently increased to 4 times the interpulse spacing. (Such scanning is materially different to that introduced by US Patent 5411502 wherein the interaction mechanism itself is specifically controlled by the rapid scanning of a cw beam. The scanning referred to in the present invention has no effect on the interactive mechanism which results from the nature of the pulse sequences and the tightly focussed beam).

The water content of both enamel and dentine is significantly less than that of soft tissue. The water spray enhances the surface water in the region of the impact area and thus assists the absorption of the

laser energy. It also provides an additional and important heat sink which is effective in ensuring both virtually no cracking to the surrounding enamel and no significant temperature rise within the underlying tissue.

A CO_2 laser set to operate within this combination of parameters defined herein satisfactorily drills enamel and dentine without cracking or pulpal heating. Experimentally this has been demonstrated by varying the pulse duration Tp, the gap between pulses in a burst Tg, the number of pulses in a burst Nb and the burst repetition frequency to identify an optimum combination of parameters for both enamel and dentine. Whilst an optimum set can be identified an effective and safe interaction can be achieved over a reasonable range of each individual parameter. For example enamel is best addressed with a lower Nb and shorter Tp. Softer material such as carious dentine is less demanding and can tolerate more and longer pulses in each burst.

This has been determined that pulse durations (Tp) from 100μs to 700μs are effective in removing hard tissue but preferably within the range 200 to 500μs. These parameters have to be offered in a group or burst of pulses. This burst provides clean removal of tissue at a significant rate given that the pulse separation is between 200 and 1000μs but is preferably between 250 and 600μs and most preferably 250 to 350μs. The preferable number of pulses within a burst lies between 1 and 10 most preferably between 1 and 5 for enamel removal and 2 and 10 for dentine removal.

The repetition rate of the bursts is within a range between 100hz and 0, preferably between 75hz and 10hz

and most preferably 50hz to 30hz.

This mode of operation of a CO_2 laser provides a materially different interaction to that achieved with a standard superpulse system (typically 600μs pulse durations at 500Hz rep rate). That the use of the combination of parameters described above enables a low power nominally cw CO_2 laser to drill enamel and that this is non-obvious in the light of accepted current perceptions. It has been noted that CO_2 laser operation of 9.6μm may be beneficial in the removal of hard tissue because of an enhanced absorption at that wavelength in hydroxyapatite, the principal inorganic matrix of enamel. Fowler, B.O. et al Arch. Oral. Biol. 1966; 11:477-492 infrared spectra of hydroxyapatites... Fowler, B.O. Inorganic Chem. 1973; 13:207 infrared studies of apatites. A laser operating at 9.6μm in a mode within the range of parameters described in this application may be effective.

The benefits of a system according to this application are in the provision of a lower cost laser drill and one which may be also configured to operate cw or superpulsed, within the same unit, to provide the well proved ability of CO_2 lasers to effectively cut soft tissue.

Example

The pulse shape, grouping and frequency is controlled by electronic drives to the laser power supply. One embodiment of the system including laser head power supply and electronic controls is shown in figure 1. The main console 1 contains these components and a particular form of scanning arrangement, 4. The beam is conducted to the handpiece 3 which includes the

water spray nozzle, via the articulated arm 2. The arm contains lensing such that the beam scanning pattern produced by the arrangement 4 in the console 1 is reproduced at the handpiece tip. Figure 2 shows one particular form of the scanning arrangement. The beam is conducted via deflectors 3, 4 and 5 to the articulated arm. In doing so the beam passes through the lens assembly 2 which is caused to rotate by gearing and a belt to stepper motor 1. If the rotational axis of the lens are not coincidental with the beam axis then the focal point describes a circle. The diameter of the circle may be adjusted by altering the amount by which the lens optic axis is displaced from the rotational and beam axis. (Other forms of scanning arrangements could be adopted including the use of vibrating mirrors and the scanning could take place elsewhere in the system, for example near the handpiece). A visible indicator beam is provided by a diode laser (7) combined coaxially with the invisible CO_2 laser beam using the combining optic (6).

A CO_2 laser drill operating at $\lambda = 10.6\mu m$ delivers $250\mu s$ pulses with the number of pulses in a burst being selected by the user being between 1 and 8. The gap between pulses in a burst is $350\mu s$ with a burst frequency of 40Hz. In use for dental drilling 3 pulses per burst is recommended for drilling enamel, 7 for dentine or caries and 1 for clean up.

In summary the tailoring of the output of a CO_2 laser to provide groups of pulses having overall parameters within the bands specified above in a scanned tightly focused beam provides effective carbon free drilling of teeth.

The embodiment described above offers advantages in

terms of simplicity and cost over existing systems. In addition it offers significant clinical advantages in that, whilst set to provide typically encountered drill hole requirements, resetting to allow finer holes or cuts can be readily achieved through control of the scanner. Such fine cuts may find application in other disciplines and procedures for example in carrying out surgery on the microbones on the ear. A further advantage is that, in the same system, by returning to the conventional mode of operating the laser, the system can then be used for soft tissue surgery.

By changing the size of the scanned pattern a further application of the tailored pulse grouping would be to the fine surface ablation of epidermis as required in the procedure known as laser dermabrasion.

Claims

1. A a CO_2 laser system for ablation of tissue comprising a laser head, and control means whereby a focused laser beam is produced in organised bursts of pulses from the laser head to an area of tissue to be ablated.

2. A system as claimed in Claim 1 comprising scanning means by which the focused beam traverses a defined area such as an area of tissue to be ablated.

3. A method for the controlled ablation of tissue comprising the steps of delivering a focused laser beam from a CO_2 laser in organised bursts of pulses to the tissue to be ablated.

4. A method as claimed in Claim 3 comprising a step whereby the focused laser beam scans the area to be ablated.

5. A method as claimed in Claim 3 or 4 wherein the wavelength (λ) of the laser pulses is between 9 and 11μm.

6. A method as claimed in any of Claims 3 to 5 wherein pulse duration is between 100-700μs.

7. A method as claimed in any of Claims 3 to 5 wherein a burst comprises between 1 and 10 pulses.

8. A method as claimed in any of Claims 3 to 7 wherein the pulse in a burst are separated by between 200 and 1000μsec.

9. A method as claimed in any of Claims 3 to 8 wherein pulse separation is between 25 and 600μs, 250-350μs.

10. A method as claimed in any of Claims 3 to 9 wherein pulse separation is between 250-350 μs.

11. A method as claimed in any of Claims 3 to 10 wherein burst repeat frequency may be between 10 and 100Hz.

12. A method as claimed in any of Claims 3 to 11 wherein burst frequency is between 30-50 Hz.

13. A method as claimed in any of Claims 3 to 12 wherein 10 to 50mJ of pulse energy is delivered in a beam focused to a diameter of typically 300μm.

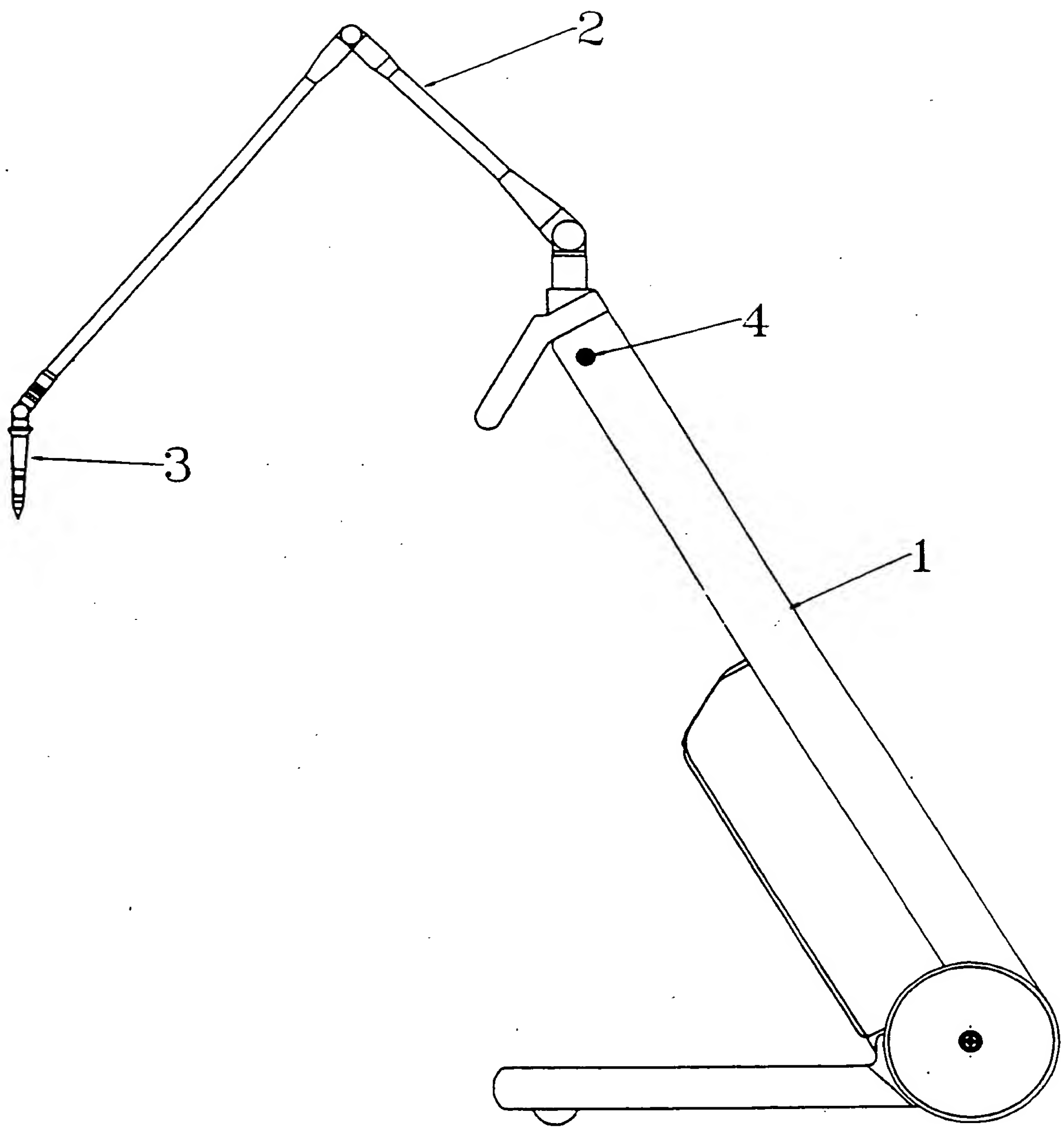

FIGURE 1

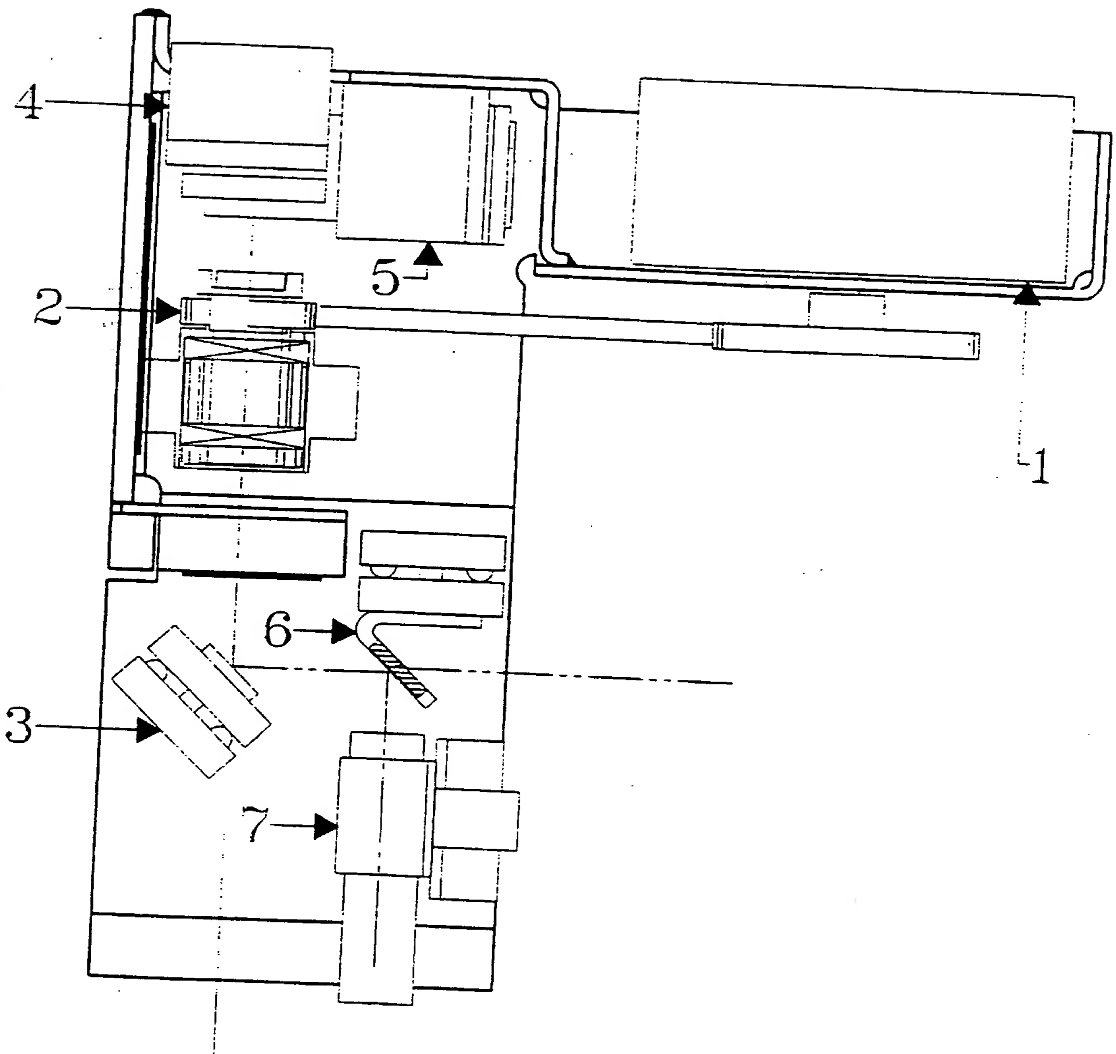

FIGURE 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/01002

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61B17/36 A61C1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61B A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,4 638 800 (MICHEL) 27 January 1987 see column 5, line 65 - column 6, line 3 see column 14, line 12 - line 16 see column 18, line 36 - line 47 ---	1,2
Y	WO,A,94 26203 (PATEL) 24 November 1994 see page 12, line 31 - page 13, line 7; claims 2,4 ---	1,2
A	EP,A,0 256 671 (NOBLE) 24 February 1988 see page 5, line 6 - line 9 see page 8, line 15 - page 9, line 8 ---	1
A	US,A,5 207 671 (FRANKEN ET AL.) 4 May 1993 see claims 1,2 ---	1
A	US,A,5 321 715 (TROST) 14 June 1994 see claims 10,21 -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
9 September 1996	16.09.96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Glas, J

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB96/01002

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 3-13
because they relate to subject matter not required to be searched by this Authority, namely:
PCT Rule 39.1(iv) Method......surgery

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 96/01002

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4638800	27-01-87	NONE		
WO-A-9426203	24-11-94	EP-A-	0696905	21-02-96
		GB-A-	2279569	11-01-95
EP-A-256671	24-02-88	DE-A-	3783290	11-02-93
		US-A-	4913132	03-04-90
US-A-5207671	04-05-93	US-A-	5342352	30-08-94
US-A-5321715	14-06-94	WO-A-	9424950	10-11-94